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JUNE 1966

FLUTTER MODEL TEST REPORT

XV-5A

LIFT FAN FLIGHT RESEARCH AIRCRAFT PROGRAM

CONTRACT NUMBER DA44-177-TC-715

GENERAL ELECTRIC

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ADVANCED TECHNOLOGY & DEMONSTRATOR PROGRAMS DEPARTMENT
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO 45215

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1.0 SUMMARY

This report covers the wind-tunnel testing, in the flutter regime of a dynamically similar model of the XV-5A Lift-Fan Research Aircraft. The test was restricted entirely to an investigation of the wing-fuselage combination and as such no empennage was represented. Test objectives were slanted toward verification of previous analytical investigations (Reference 1), with close attention paid to uncovering any transonic effects which might have been crudely represented analytically.

The tests were completed to the point of achieving a 5 percent margin on equivalent speed for the highest aileron rotational frequency studied, approximately 18.9 cps. One actual case of flutter occurred, at M = 0.75 and at a dynamic pressure (q) of approximately 600 psf for an aileron rotational frequency of 14.9 cps. A second case of flutter occurred at M = 0.75 and a q greater than 600 psf for an aileron rotational frequency of 16.1 cps; however, this latter case of flutter was not considered valid due to the apparent fatiguing of an aileron spring bracket, resulting in essentially a free floating surface.

2.0 INTRODUCTION

This report summarizes the results of the experimental wind-tunnel investigation of the flutter characteristics of the wing-fuselage combination of the U.S. Army XV-5A Lift-Fan Research Aircraft. The XV-5A is a V/STOL aircraft designed for research flight testing of the General Electric X353-5 Lift Fan Propulsion System.

The flutter model so tested had a length ratio of 17.5 (ℓ_m/ℓ_a = 1/17.5) with a density ratio of approximately 2.0 (ρ_m/ρ_a = 2.0). The model was designed and fabricated by "Dynamic Devices, Incorporated", Dayton, Ohio. Reference 2 presents the design and construction specification.

The actual testing was conducted at the Chance Vaught Corporation High Speed Wind Tunnel Dallas, Texas. The tunnel used is an atmospheric exhaust, blow-down tunnel with a 4' by 4' test section. Further description of the tunnel characteristics may be found in Reference 3.

The design and fabrication period extended through the fall and winter of 1962 - 1963 with the actual testing taking place during the period of 8 February through 14 February 1963.

3.0 MODEL DESIGN PARAMETERS

Initial considerations of the flutter aspects of the XV-5A led to the belief that the wing would be critical in view of the cutout required for lift fan placement. Initial analytical investigations verified the design with the 4g flight configuration being the critical configuration selected for wind-tunnel evaluation (Reference 1). Two sets of wings were designed and fabricated to meet the stiffness requirements of the 4g flight configuration. Since aircraft rigid body degrees of freedom were considered important (Reference 1), the model was so designed to incorporate these degrees of freedom. The fuselage was represented by a single spar which simulated the stiffnesses of the vehicle. Masses were arranged along the beam to provide the proper mass and inertia distribution (including empennage). The external shape of the fuselage was scaled exactly to provide the proper pressure distribution over the wings. The basic wing was fabricated similarly to the actual structure i.e. two spar construction, skin and forward nose box. The lift fans were scaled with respect to mass and inertia effects and were attached to the wing spars and fuselage beam through a three-point suspension system.

Scale factors utilized for the model are presented in Table I. These scale factors were derived from a consideration of the dynamic pressures desired and the tunnels initially selected for testing. Figure 1 shows various aspects of the model during its fabrication stage. It is to be noted that the fuselage shell is a fixed item (fixed to the tunnel sting) while the beam which represents the fuselage both elastically and inertially (including empennage) is suspended from the fixed shell through flexures to provide the required rigid body freedoms. Each wing (semi-span) is attached to the fuselage beam at three points, the forward and aft spar attachment points and through the leading edge box. These points may be seen in Figure 1b.

Control surfaces (ailerons and flight tabs) were dynamically scaled with actuator stiffness and control system stiffness simulated by interchangeable flexures to provide variable frequencies. The flight tab was hinged to the aileron in such a manner as to provide the actual gearing between aileron and tab. Provisions were made in the aileron structure to allow for mass balancing.

Instrumentation consisted of strain gages mounted on both the front and rear wing spars (root) whereas the ailerons and lift fans were instrumented with magnet-coil devices.

3.1 STATIC TESTING

To confirm the stiffness and mass characteristics, the wings were subjected to several tests. Each semi-span wing was evaluated from a stiffness view point to insure a correct distribution. Figure 2 depicts one test set-up wherein structural influence coefficients of the model wing were measured, reduced and compared to calculated influence coefficients of the full size wing. Since slopes were measured (mirror technique), an analytical procedure was developed wherein the deflections were related to the slope of the bending curve through a Lagrangian interpolation scheme. In the second case, deflections under load were recorded from dial gages and compared to the calculated coefficients. Initial tests indicated the models were too stiff which necessitated remachining of a portion of the wing spars and removal of a portion of the skin from the outer panel. After several cycles of testing, the wings were considered satisfactory.

Since the design gross weight condition of 9200 pounds was chosen as the weight condition to be tested, the model mass distribution was aimed at meeting this condition. To insure a proper mass distribution of a wing semi-span, a sample wing was cut up by the model builder, each piece weighed and the mass distribution adjusted to conform to that calculated for the full scale vehicle.

3.2 DYNAMIC TESTING

The last phase of the model design phase consisted of vibrating the model both as a cantilever and as a free-free vehicle, i.e., with wings attached to the fuselage beam under its elastic constraints. Aileron frequencies were measured and were as follows:

$$f_1 = 18.9 \text{ cps}$$

$$f_2 = 16.1 \text{ cps}$$

$$f_3 = 14.9 \text{ cps}$$

This initial vibration test plus later vibration tests with the model installed in the test section at the wind tunnel provided some indication of the modal

characteristics for use in flutter correlation. Some of the basic frequencies and modal characteristics of the model (tunnel sting supported) were as follows:

Wing Number 1 (Aileron frequency - 14.9 cps)

SYMMETRIC EXCITATION	ANTISYMMETRIC EXCITATION
f_1 = 7.4 cps - 1st fuselage bending	f_1 = 6.8 cps - 1st fuselage bending
f_2 = 8.5 cps - Wing bending	f_2 = 8.5 cps - Fuselage torsion
f_3 = 14.7 cps - 2nd fuselage bending	f_3 = 14.6 cps - Wing bending
f_4 = 22.9 cps - Wing torsion	f_4 = 18.5 cps - 19.6 cps - Aileron rotation - wing torsion
	f_5 = 22.5 cps - Wing Torsion

Wing Number 2 (Aileron frequency - 19.35 - 16.62 cps)

SYMMETRIC EXCITATION	ANTISYMMETRIC EXCITATION
f_1 = 6.8 cps - 1st fuselage bending	f_2 = 8.2 cps - Fuselage torsion
f_2 = 8.5 cps - Wing bending	f_3 = 16.5 cps - Wing bending
f_3 = 15.0 cps - 2nd fuselage bending	f_4 = 18.1 cps - Aileron rotation - Wing torsion
f_4 = 20.3 cps - Aileron rotation - Wing torsion	f_5 = 23.6 cps - Wing torsion

Figure 3 shows a semi-span wing being vibrated as a cantilever. The dark line running down the wing and aft through the aileron is the node line. This was achieved by using salt or some similar substance, which upon excitation of the model gathers along paths of zero displacement. Figure 4 depicts the model mounted in the tunnel prior to start of the tunnel phase of the program.

4.0 WIND TUNNEL PARAMETERS

The Mach Numbers considered for the test was from approximately 0.5 to 1.04. Figure 5 depicts the XV-5A flight envelope in terms of airplane dynamic pressure. Also shown are the 5 percent and 15 percent margins on equivalent air speed The test was so arranged to cover conditions wherein the Mach Number was held constant and the density increased during a run to some predetermined value; this was accomplished by what was termed a ramp increase in the dynamic pressure. The second condition programmed a constant static pressure for a variable Mach Number.

4.1 TEST OUTLINE

The initial test plan was broken down into two phases; these phases being consistent with the airplane's lateral control system. The first phase, called the power mode, was to investigate the aileron rotational restraint required for a flutter free system. The second phase, called the manual mode, would deal with the aileron in an emergency condition i.e. all hydraulic pressure is lost and the lateral control system had reverted to a manual mode. For the latter phase, the aileron flexures were to be removed and investigations carried out to determine the control system restraint and mass-balance required for a flutter free system. Each phase was broken down as follows:

Power Phase

Configuration 1 — Rigid aileron spring (aileron locked out)
Nominal control system spring
Zero mass-balance

Configuration 2 — Nominal aileron spring
Nominal control system spring
Zero mass-balance

Configuration 3 — 50 percent nominal aileron spring
Nominal control system spring
Zero mass-balance

Manual Phase

Configuration 1 — No aileron spring
Nominal control system spring
Aileron statically balanced

Configuration 2 — No aileron spring
1.5 nominal control system spring
Aileron statically balanced

Configuration 3 — No aileron spring
0.5 nominal control system spring
Aileron statically balanced

Configuration 4 — No aileron spring
Nominal control system spring
Aileron statically balanced as determined from previous configurations.

4.2 TEST RESULTS

Initial tests were confined to the Power Phase and after vibrating of the model and establishment of the aileron rotational frequencies, it was determined that the aileron frequencies did not meet the requirements as spelled out in the test outline, i.e. rigid, nominal and 50% of nominal. Nominal had been obtained from frequency calculations and was shown to be approximately 15.0 cycles per second for the coupled aileron and tab frequency (assuming stick-fixed).

The first tunnel runs were slanted toward establishing a 5% margin on the envelope as shown in Figure 5. Table II lists the runs and accompanying tunnel conditons. Data recorded during each run consisted of tunnel stagnation pressure (P_o) and temperature (T_o) in addition to model vibration data which was recorded on an oscillograph. Movie coverage of each run was also made for later study.

By using isentropic flow relationships, the test section tunnel parameters, ρ, V, P_s, T_s were calculated with the stagnation density calculated from the stagnation pressure and temperature. Reference 3 tabulates for each run, the appropriate tunnel parameters.

Each wing was designated a number for identification purposes as also were each of the aileron springs for which a definite rotational frequency

was established. Spring A corresponded to 18.9 cycles per second, B to 14.9 cycles per second and C to 16.1 cycles per second.

5.0 DISCUSSION AND CONCLUSIONS

As indicated in Table II, eighteen runs were expended on Model 2A; Number 2 wing with A aileron spring (18.9 cycles per second). As it turned out, it was impossible to obtain a locked out aileron with the current model design, so it was decided to run with the highest aileron frequency available. By sequencing of different runs, ramping the dynamic pressure or Mach Number, the 5% margin on the flight envelope was cleared with this model. At M = 0.79, the model was lost due to excessive loading on the wing. This was not considered a flutter condition. The next five runs were devoted to establishing frequency requirements (aileron rotational restraint). Here a case of flutter occurred at a Mach Number of 0.75 and at a dynamic pressure (q) of approximately 600 psf. During these runs, Model 1B was used which was the Number 1 wing with the B aileron spring (14.9 cycles per second). The next run was accomplished using also the Number 1 wing with the C aileron spring (16.1 cycles per second). During this run, the model was lost also due to flutter, but the run was not considered valid since an aileron spring support bracket had fatigued, resulting in essentially a free-floating surface. From the remaining parts of Number 1 and 2 wing, a third model was constructed and aileron spring C installed (16.1 cycles per second). The run was attempted at M = 0.75 with a ramp in dynamic pressure (q), but the model was destroyed through structural failure during the ramp, thus ending the test.

From a consideration of the tests, it was concluded that the XV-5A wing was adequate from a standpoint of flutter for the proposed envelope and that a 5% margin had been demonstrated. This conclusion rests heavily also on the assumption that the aileron rotational frequency is high, of the order of 20 cycles per second or greater.

6.0 REFERENCES

1. Preliminary Flutter Analysis, olume I - Wing, Report No. 163, November, 1965.

2. Krupnick, M.; Design and Construction Specification for a Transonic Flutter Model of the Ryan Model 143 Wing; Ryan Report No. 62B108, 10 August 1962.

3. Simon, E.H.; Corrected Title - Flutter Tests on a 1/17.5 Scale Ryan VZ-11 Wing Model in the Mach Range of .5 Through .95, Chance Vought Corporation, Report No. HSWT Test 103, May, 1963.

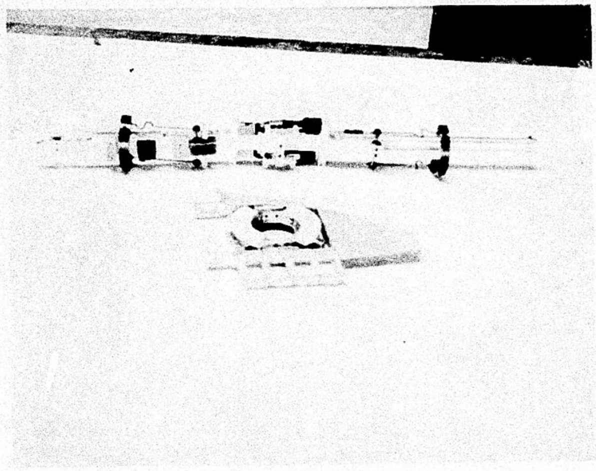

Figure 1a Fuselage Beam

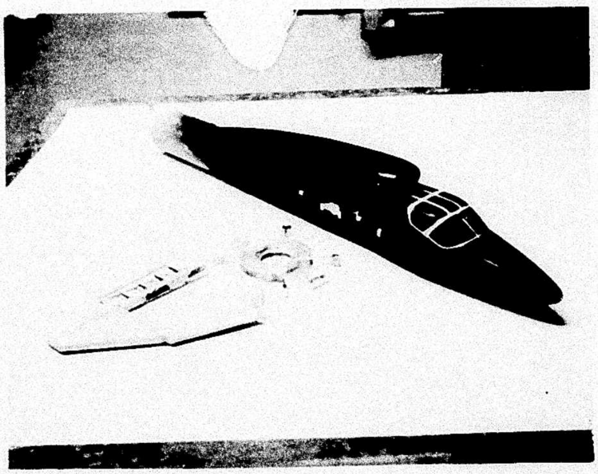

Figure 1b Wing Model and Lift Fan Model

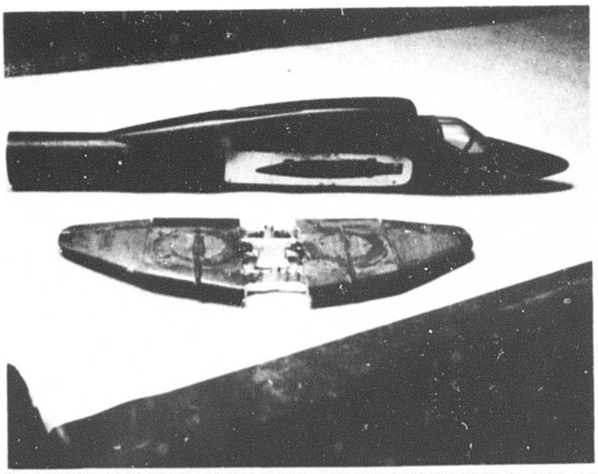

Figure 1c Complete Wing and Fuselage Model

Figure 1 Model Fabrication

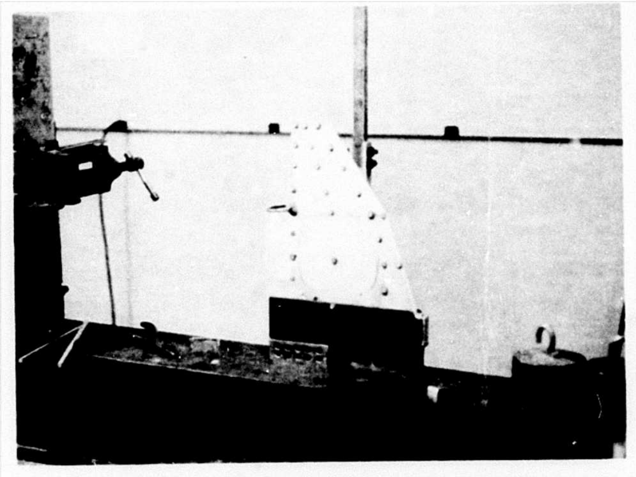

Figure 2 Model Static Testing

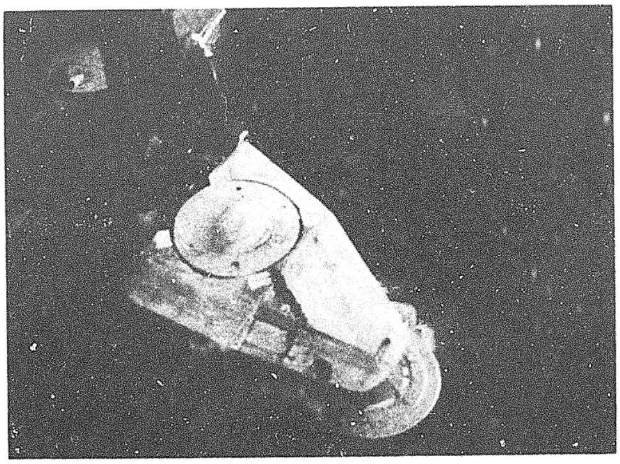

Figure 3 Model Dynamic Testing

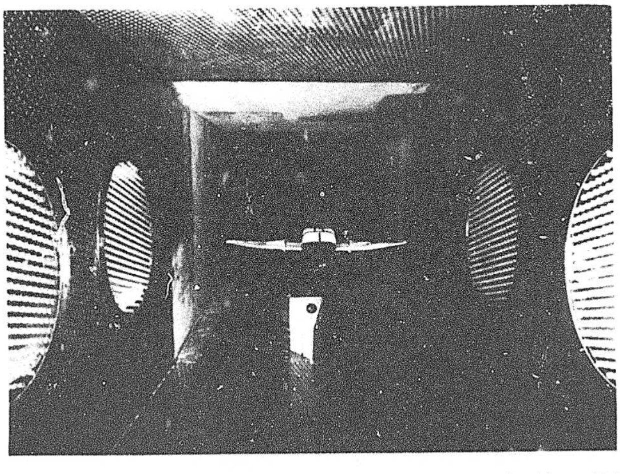

Figure 4 Tunnel Installation of XV-5A Flutter Model

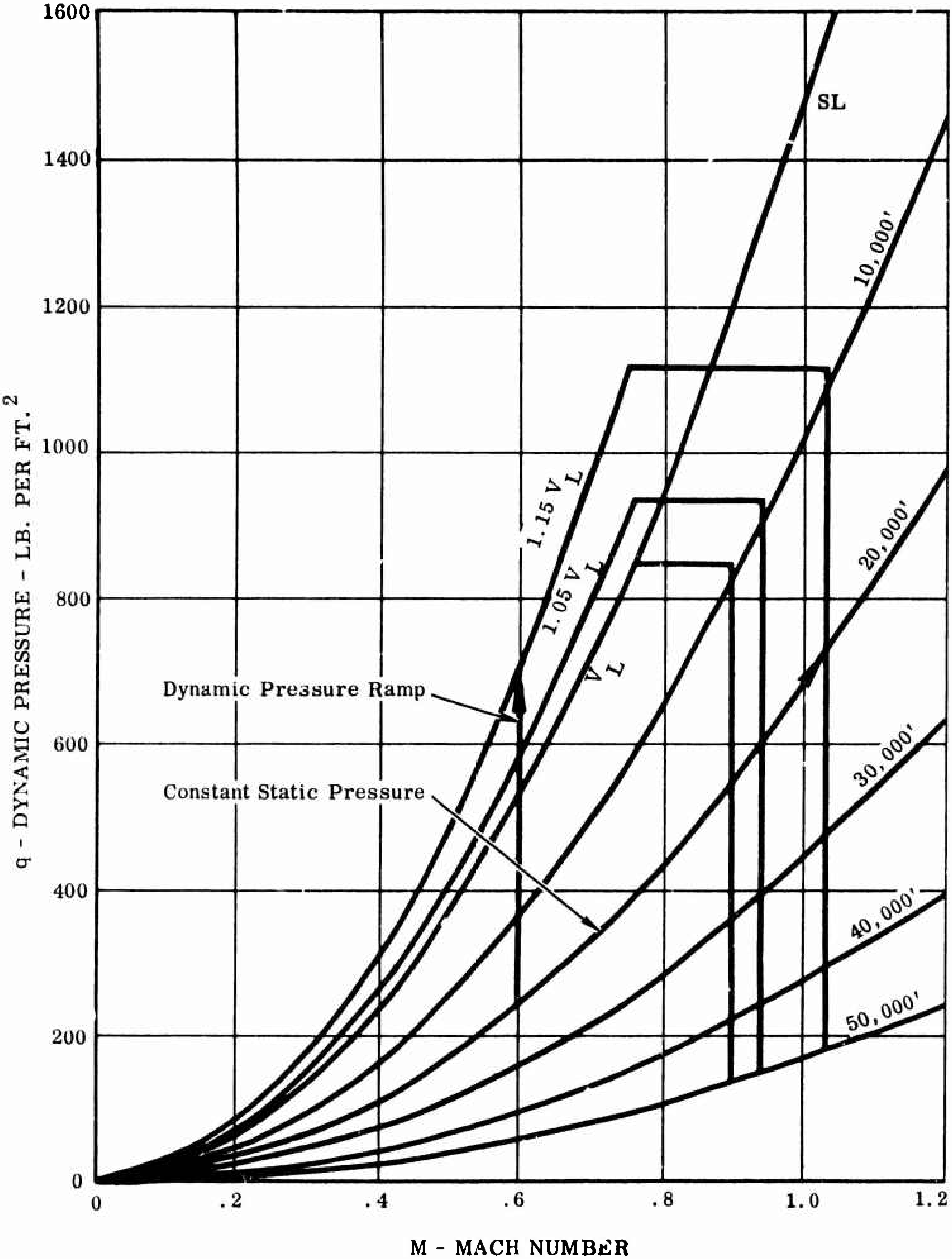

Figure 5 XV-5A Flight Envelope

TABLE I

Model Scale Factors

Length: ℓ_m / ℓ_a = 1/17.5 (20.6" model wing span)
Velocity: $V_m / V_a = 1.0$
Density: $\rho_m / \rho_a = 2.0$
Dynamic Pressure: $q_m / q_a = 2.0$
For $\mu_m / \mu_a = 1.0$ (mass ratio)
Force: $P_m / P_a = 0.006531$
Displacement: $\delta_m / \delta_a = 1/17.5$
Weight: $W_m / W_a = 0.169271$ W_m - grams; W_a - pounds
Stiffness: $EI_m / EI_a = 0.021324 \times 10^{-3}$
Inertia: $I_m / I_a = 0.552703 \times 10^{-3}$ I_m - grams-in^2, I_a - lb-in^2
Frequency: $\omega_m / \omega_a = 17.5$
Flexibility Influence Coefficient: $C_m^{\delta\delta} / C_a^{\delta\delta} = 8.75$
m - model; a - airplane

TABLE II

TUNNEL RUN SCHEDULE

Run No.	Model Configuration	Mach No.	α Deg	ϕ Deg.	P_o PSIA	P_s PSIA	q PSF	q PSI	Remarks
1	2A	0.5	-1° 10'	0	23.5	19.8	400	2.778	Trim Run
2		0.5			23.5	19.8	400	2.778	Repeat of Run #1 - Bad Zero Calibration
3		0.5			23.5 - 36.5	19.8 - 32.5	400 - 820	2.778 - 5.694	
4		0.5	-1° 10'						Repeat of Run #3 - Ramp Time Down Too Fast
5		0.5	-41'		23.5 - 36.5	19.8 - 32.5	400 - 820	2.778 - 5.694	Repeat of Run #4 - Sting Angle of Attack Set
6		0.75			20.5	14.1	800	5.556	Trim Run
7		0.75	-41'		20.5 - 47.0	14.1 - 32.4	800 - 1870	5.556 - 12.99	
8		0.90	0		25.0	14.8	1200	8.333	Trim Run
9		0.90			25.0 - 39.0	14.8 - 23.0	1200 - 1870	8.333 - 12.99	
10		0.95			19.7	11.0	1000	6.944	
11		0.70 - 0.95			19.5 - 25.1	14.0	695 - 1280	4.826 - 8.889	
12		0.70			29.1	21.0	1030	7.153	
13		0.80 - 0.95			32.0 - 37.6	21.0	1350 - 1880	9.375 - 13.06	
14									Repeat of Run #13 - Tunnel Conditions Not Reached
15									Repeat of Run #14 - Ramp Time Down Too Fast
16		0.80 - 0.95			32.0 - 37.6	21.0	1350 - 1880	9.375 - 13.06	Repeat of Run #15 - Tunnel Conditions Not Reached
17		0.70			41.0	29.5	1460	10.14	
18	2A	0.79			44.6	29.5	1870	12.99	Lost LH Wing
19	1B	0.50			23.5	19.8	500	3.472	Trim Run
20		0.50			23.5 - 36.5	19.8 - 32.5	400 - 820	2.778 - 5.694	
21		0.75	0		20.5	14.1	800	5.556	Trim Run
22			-10'		20.5 - 30.7	14.1 - 21.0	800 - 1200	5.556 - 8.333	
23	1B				30.7 - 47.0	21.0 - 32.4	1200 - 1870	8.333 - 12.99	Lost LH Aileron and RH Tab
24	1C								Lost RH Wing
25	1L - 2RC	0.75	-10'	0	30.7 - 47.0	21.0 - 32.4	1200 - 1870	8.333 - 12.99	Lost LH and RH Wing

α - Sting Angle of Attack
ϕ - Sting Side-slip Angle
P_o - Stagnation Pressure
P_s - Free Stream Static Pressure
q - Dynamic Pressure